CONSIDERATIONS FOR THE COMMERCIALIZATION OF COAL BIODESULFURIZATION TECHNOLOGY

Barbara J. Zakheim
NUS Corporation
Gaithersburg, Maryland

S. Rick Gilbert
Pittsburgh Mineral and Environmental Technology, Inc.
Pittsburgh, Pennsylvania

INTRODUCTION

The adverse effects to human health and to the ecological environment caused by the release of sulfur dioxide (SO2) to the atmosphere during coal combustion have gained increasing attention due to the acid rain debate. Control of SO2 emissions, however, have been regulated under various federal, state, and local standards for well over ten years. The 1977 amendments to the Clean Air Act (CAA) introduced Environmental Protection Agency (EPA) regulation of new utility coal-fired boiler emissions under the New Source Performance Standards (NSPS) of 0.6 lbs/mm BTU. Compliance with these standards and National Ambient Air Quality Standards (NAAQS) have required that many utilities purchase coal based on sulfur content, often more expensive feedstocks, and also invest in costly flue gas desulfurization processes, especially scrubbers.

Currently the EPA is in the midst of promulgating SO2 control regulations for the industrial boiler market, which mandate a 90 percent reduction of emissions from all new coal industrial and commercial boilers regardless of the sulfur content of the coal. Compliance with these regulations may prove very difficult for industrial boiler owners. For example, boiler emissions would have to be lowered to 0.6 lbs/mm BTU when using 3 percent sulfur eastern coal. This would cause fuel switching to natural gas, rather than expensive coal cleaning or flue gas treatments.

The pre- or post-combustion removal of sulfur from coal, therefore, is a regulatory driven necessity but is constrained by technological and economic difficulties. Technologies that are commercially available include a variety of physical and chemical coal cleaning techniques and several flue gas treatment processes. Table 1 lists the most common, commercially available technologies with an approximation of their efficiencies and costs. As shown, both capital and operating costs for these processes are quite significant, and in most cases remove less sulfur than required to meet regulations. The successful commercial introduction of any new technology into this marketplace, therefore, requires both efficient sulfur removal and cost competitiveness.

BIODESULFURIZATION OF COAL

One technology for coal desulfurization that is under development, but still far from a commercial reality, is biological treatment. In the past few years, several studies have identified the technical status of coal biodesulfurization research, listing published results of laboratory scale experiments both in the United States and overseas (National Bureau of Standards, 1986; Battelle Pacific Northwest Laboratories, 1986; Couch, 1987). These studies refer to experimental results published since 1914, although the majority have appeared in the past twelve years. Most of these experiments have been concerned with the microbiology and coal chemistry aspects of coal biodesulfurization and very few have looked at the engineering, process, and economics aspects. Notable examples of this latter category include studies by Bos (1985), Dugan (1985), and Sproull (1986).

Results from these studies indicate that pyritic sulfur removal using the acidophilic organism Thiobacillus Ferroxidans has been achieved widely, with over 90 percent removal reported by many researchers. In addition, these sulfur oxidizing microbes remove ash and some metals during the biodesulfurization process. Removal of organic sulfur is more difficult; the use of thermophilic organisms have apparently reduced the organic sulfur component of some high sulfur coals by up to 30 percent (Chandra, 1987; Isbister 1986). What is clear from these studies is that biological treatment provides no utopian solution to the coal desulfurization problem and may only be part of a more complex, multifaceted process. Furthermore, biological treatments may be more suitable for some coals than others and may not deal with both the organic and inorganic sulfur present in coal. On the other hand, there is some indication that biological removal of pyrite may be economically competitive with physical coal cleaning methods, especially as operations and maintenance costs will be limited and a greater percentage of sulfur will be removed.

Given this current status, therefore, what can be done to bring coal biodesulfurization technology to the marketplace within a timeframe that is compatible with the regulatory drivers? In answering this question, it is important to understand the prominent issues impeding the progress of coal bioprocessing research:

- Transfer of fundamental studies to pilot or demonstration activity -- emphasis remains on benchtop studies and, as shown in Figure 1, only about 15 percent of these have given any attention to either process design, engineering, or economics.
- Low level of research funding and emphasis --although clean coal technologies are receiving large-scale

funding from the government, the Electric Power Research Institute (EPRI), and the private sector, fundamental research in biotechnology lags far behind the funding levels available for demonstration activities in other coal cleaning areas, flue gas treatment processes, fluidized bed combustion, or fuel cells.

- Lack of commercial biotechnology company interest -- unlike the pharmaceutical, agricultural, or metals extraction industries, coal bioprocessing leads to a low value-added product.

Overcoming the first of these impediments by transferring fundamental studies to demonstration activity will probably remove the remaining two. Quite often, not all of the components of a given process are fully developed by the inventors, but the overall concept has merit and should be tested at a larger scale. Some see this approach as risky, which it is, while others see it as an opportunity to begin tackling the next phase of problems. Hopefully, by the time the process is brought to commercialization, an acceptable solution to all of the "underdeveloped" portions of the technology have caught up. In making a case for early scale up, this paper presents examples of several industries and their own progress in commercializing biological processing. By offering these examples and comparing them to coal, it is the objective of this paper to stress performance of both applied and fundamental research early on in order to accelerate the implementation of a commercially viable process.

BENCH TO COMMERCIALIZATION -- INDUSTRY EXAMPLES

The importance of achieving a synergism between applied technology and fundamental microbiology was poignantly exemplified in the petroleum industry. When the development of the petroleum industry was in its infancy, neither the petroleum, technologists nor the microbiologists were aware of the others activities (Davis, 1967). It was in fact a Russian geologist who is credited for using bacterial hydrocarbon oxidation as a prospecting tool. He had enlisted the assistance of microbiologists who were working separately on the same problem, and their joint efforts resulted in a practical solution for petroleum exploration. In a similar fashion during the 1940's, petroleum geologists in the United States established the need to involve microbiologists to resolve issues relating to source sediments. In this case as well, those involved with the practical application solicited the assistance of those with a technical understanding of microbial interactions and, together, they engineered a timely and workable solution.

Another example involves waste water management. Even though the biological management of wastes, particularly waste waters, has been employed for centuries, a firm understanding of the principles has only been achieved in recent decades. Engineers, aided by available biological data, have successfully designed and implemented scores of aerobic waste water treatment systems, and new systems are still in the making. The proper engineering and optimization of biological water treatment systems are continuing to improve the industry as evidenced by the anaerobic bio-reactors now being developed for municipal waste water treatment (Cheremisinoff, 1987).

In the agricultural area, processes for improving crop yields and reducing infestation have also been approached with the fundamental microbiology and genetic engineering research occurring at the same time as the applied system development and the overcoming of policy and regulatory constraints.

The metals mining industry provides one of the most striking examples in recent years of a large, industrial-scale microbiological process that has been snatched from the laboratory beaker and engineered into production before "the ideal" set of microbiological data has been documented.

Much of the practical beginnings of bioextractive metallurgy in the copper industry is attributed to J. Prater, E. Malouf and other engineers at Kennecott Copper Corporation (now BP Minerals America) who, in the 1960's, initiated a dump leaching operation at Bingham Canyon to recover metal values contained in sulfide copper ores. Gleaning what biological information they needed, they successfully engineered and implemented one of the world's first and largest dump leaching operations. Initially, these engineers knew relatively little about how optimal strains of bacteria performed on model compounds, and what conditions might produce the optimal response during leaching. Nevertheless, from their efforts to get the wheel rolling, as well as those of others like them, bioleaching operations in copper and uranium have spread throughout the world. It was the iterative process of engineering design, fed by increased microbiological understanding, that led to the successful implementation of the technology.

In a similar vein, precious metals recovery from sulfide minerals made great strides once the process moved from laboratory investigation to pilot-plant development studies. A number of investigators had been involved in fundamental studies of the biooxidation of pyrite so that encapsulated gold particles could be liberated for subsequent cyanidation (Bruynesteyn, 1984; Lawrence, et. al., 1985; and Murr, et. al., 1980). A few engineering, research, and equipment companies over the past 10 years have undertaken pilot-plant scale-ups of biooxidation systems for precious metal recovery by drawing on the available biological data. Coming to grips with engineering issues such as reactor design, slurry dewatering, effluent water treatment, reagent and nutrient consumption, aeration requirements, materials of construction and interfacing the biooxidation process with pre- and post-treatment processes have led to the installation and operation of at least three commercial plants in the free world.

Feasibility studies also played an important role in establishing the economic viability and eventual plant implementation of bacterially-enhanced precious metals recovery (Marchant, 1986). It was the present author's experience that the potential for a significant return on investment by biologically treating gold-bearing concentrates prompted a large scale pilot-plant study (Gilbert, et. al., 1988). Certainly, microbiological studies are evolving along with the economics and the practical plant applications, but with a better focus toward the real needs of the process.

LESSONS FOR COAL BIODESULFURIZATION

From the above examples it can be seen that the speed of progress in bringing biotechnology to a commercial reality resulted from early scale up or applied research supporting fundamental studies. Among the reasons for this appear to be motivation and approach, especially evident in the metals extraction area. In that case, the value added by the process was relatively high, especially in bioleaching of gold and other precious metals. Further, due to this motivation of producing a valuable product, the approach to developing an efficient technology focused foremost on the process engineering and economics, utilizing available microorganisms in increasingly larger-scale demonstration programs. As a feasible process became evident, refinements to the process based on an improved understanding of the microbiology and chemistry were made.

Biodesulfurization of coal is now at the stage where pilot plant efforts should begin. By placing the carrot, cart and horse in proper order, productive progress can be made. At present, there is a shortage of engineering data to keep pace with the fundamental microbiological studies now in progress. The bulk of governmental and industrial research support has been focused on microbiological developments dealing with isolated bacteria, model compounds, and sterile coal samples. Progress and funding are now slowing so that in a few years the process development of biodesulfurization might be strictly an academic issue. A solid pilot-scale study accompanied by a thorough economical feasibility study is needed to revitalize the program.

Scale up of coal biodesulfurization experiments will provide essential data about the feasibility of such a process and its application to the numerous coal feedstocks in the market. By applying what is already known, researchers can answer some of the fundamental engineering and economics concerns that will either make or break further efforts in this field. For example:

- Can bioextraction handle large tonnages of coal? Even for industrial boiler application, the volumes of feedstocks involved are far greater than in other biotechnology applications.
- If a superbug is developed that can reduce greater levels of organic sulfur and/or pyritic sulfur will it thrive in the engineered environment?
- What are the pre- and post-treatment requirements?
- What are the environmental benefits and concerns relating to solids, liquids, and gasses involved with the process? What are the volumes of each?
- Is it economical to treat run-of-mine coal or possibly a reject stream?
- Can organic and inorganic be coupled together in the same stage, or handled separately?
- What are the supply and cost constraints of nutrients?
- What impact will coal biodesulfurization have on the overall power plant design and performance?

In terms of pyrite removal, a technical feasibility study of coal biodesulfurization carried out in the Netherlands (Bos, 1985) suggests that the process is a realistic, economic option, although probably in conjunction with other processes. Bos concluded the following:

- Coal must be milled extensively to achieve an acceptable pyrite removal without considerable carbon loss.
- Pyrite removal was achieved on all of the 17 different, worldwide coal samples tested. In addition heavy metals and varying amounts of ash were removed.
- A temperature of 30 degree C. is optiomal for T. Ferrooxidans cultures, but residence times for 90 percent pyrite removal are between 7 to 9 days.
- Long residence times and large tonnages of coal will require large reactors. He recommends a trough-shaped system similar in cross section to the Pachuca-tank reactor.
- For the treatment of 1 ton of coal in a 1 million tons of coal per year installation costs range between $9 - 16.

These results and others presented by Dugan and Sproull certainly suggest further feasibility analyses and scale up studies. In particular, economics data that include the costs and benefits of combined sulfur, ash, and metals removal must be carefully evaluated.

In conclusion, microbial studies have brought us a long way, but they will not satisfy the need to demonstrate the technology at a larger scale. Answering the engineering questions could well be the bucket of cold water that douses degree has been earned but experience is needed. It is up to the research community to gain the experience from scale up and demonstration programs before earning a higher degree in the fields of microbiology and chemistry.

REFERENCES

Battelle Pacific Northwest Laboratories, "Biologic Coal Beneficiation-Literature Review", EPRI Report AP-4834, 1986.

P. Bos, et. al., "A Dutch Feasibility Study on Microbial Coal Desulfurization", presented at the International Symposium on Biohydrometallurgy, Vancouver, BC, August, 1985.

A. Bruynesteyn, "Bio-leaching of Refractory Gold-Silver Ores", Presented at the 14th Annual Hydro-metallurgical Meeting, CIM, Ontario, Oct. 1984.

D. Chandra and A. Misra, "Desulfurization of Coal by Bacterial Means", Proceedings of the Biological Treatment of Coals Workshop, Vienna, VA, July, 1987.

P.N. Cheremisinoff, Wastewater Treatment, pp 279-324, Pudvan Publishing Co., 1987.

G. Couch, "Biotechnology and Coal", IEA Coal Research Report OCTIS/TR 38, 1987.

J.B. Davis, Petroleum Microbiology, pp 1-15, Elsevier Publishing Co., 1967.

P. Dugan, "Economics of Coal Desulfurization", Proceedings of the Biological Treatment of Coals Workshop, Herndon, VA, June, 1986.

S.R. Gilbert, et. al., "Comparative Economics of Bacterial Oxidation and Roasting as a Pre-treatment Step for Gold Recovery from an Auriferous Pyrite Concentrate", CIM Bulletin, February, 1988.

J. Isbister, "Biological Removal of Organic Sulfur from Coal", Proceedings of the Biological Treatment of Coals Workshop, Herndon, VA, June, 1986.

R.W. Lawrence, et. al. "Biological Pre-oxidation of a Pyrite Gold Concentrate" Frontier Technology In Mineral Processing, AIME, 1985.

P.B. Marchant, "Commercial Piloting and the Economic Feasibility of Plant Scale Continuous Biological Tank Leaching at Equity Silver Mines Limited", Fundamental and Applied Biohydrometallurgy, Elsevier, 1986.

L.E. Murr, et. al., Metallurgical Applications of Bacterial Leaching and Related Microbiological Phenomena, Academic Press, New York, 1978.

National Bureau of Standards, "Processing of Coal with Microorganisms", EPRI Report AP-4472. 1986

NUS Corporation, "An Assessment of Microbial Coal Desulfurization and Microbial Solubilization Experimental and Economics Data", Prepared for EG&G, Idaho, Inc., March, 1988.

R. Sproull, et. al., "Enhancement of Coal Quality by Microbial Demineralization and Desulfurization", Proceedings of the Biological Treatment of Coals Workshop, Herndon, VA, June, 1986.

Table 1: Commercially Available Coal Desulfurization Technologies

TECHNOLOGY	PERCENTAGE SULFUR REMOVAL	OP. COST ($/T)	CAP. COST ($/KWE)
TRW Gravimelt	80-90	30	82
Flue Gas Desulfurization	Up to 90	7-12	150-200
Physical Coal Cleaning	30-40	4-6	50
Advanced Flotation	53	25	110
Oil Agglomeration	49	23	85
Fine Coal, Heavy Medium	59	21	98

Source: Pittsburgh Mineral and Environmental Technology Internal Documentation

Figure 1: Disciplinary Focus of Coal Biodesulfurization Literature